Research Proposal

On

Integration of Solar PV in Smart Grid System

Submitted for Comprehensive Examination in
Partial Fulfillment for the Requirement of the degree of

Doctor of Philosophy
By

Pramod Kumar Bhatt
Research Scholar
(En. No. - 140298)

Under the Supervision of

Prof (Dr.) J. V. Desai
(Professor& Dean)
College of Engineering and Technology
Mody University of Science and Technology, Lakshmangarh

CONTENTS

1 INTRODUCTION: SMART GRID

2 ISSUES AND CHALLENGES IN EXISTING POWER SYSTEM

3 GRID CONNECTED SOLAR PV

4 TECHNICAL CHALLENGES IN SOLAR PV INTEGRATION

5 LITERATURE REVIEW

6 PROPOSED RESEARCH WORK PLAN

7 RESEARCH PROGRESS

8 REFERENCES

1 INTRODUCTION: SMART GRID

1.1 Introduction

A smart Grid is the judicious but strong combination of the Electrical Grid with the Information & Communication Technology. It is a new way of how energy is transmitted, distributed, planned and measured. It supports the monitoring and management of renewable energy systems through a two-way communication system and distributed generation. The European Technology Platform defines the Smart Grid as: A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it i.e. Generators, consumers or both in order to efficiently deliver sustainable, economic and secure electricity supply. According to the U.S. Department of Energy: A smart grid uses digital technology to improve reliability, security, and efficiency (both economic and energy) of the electrical system from large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources. Working definition of smart grid is that the smart grid is an advanced digital two way power flow power system capable of self-healing, adaptive, resilient, reliable and sustainable with foresight for prediction under different uncertainties. It is equipped for interoperability with present and future standards of components, devices and systems that are cyber-secured against malicious attack. Smart grid vision demands the integration of different renewable energy sources in one component. Therefore Challenges in the integration are obvious as renewable energy sources are highly variable with respect to many electrical parameters. The smart grid must absorb the variability of these sources through critical technological solutions.

1.2 Comparison between traditional grid and smart grid

Traditional Grid	Smart Grid
Electromechanical devices	Digital/microprocessor devices
Congestion and bottlenecks	Security and sustainability
Conventional meters	Smart Meters
Centralized generation	Distributed generation
Manual restoration	Self-healing
One-way power flow	Two-ways power flow
One-way information flow	Two-ways information flow
Limited integration of renewable energies	Full integration of renewable energies
Estimated load profile	Accurate forecasting
Estimated billing	Precise billing

2 ISSUES AND CHALLENGES IN CONVENTIONAL POWER SYSTEM

The conventional power system is facing number of challenges such as

- New dynamics of future demand and supply due to new type of loads.
- Weak grid system and aging infrastructure.
- Complex, Meshed interconnected grids.
- Variable Demands of consumers.
- Congestion in the lines.
- Electromechanical protection system which is slow and sluggish.
- Poor reliability and power quality.

3 GRID CONNECTED SOLAR PV

The sunlight is converted to DC power electricity via solar arrays and the generated DC power is in turn converted to AC power through the PCU. AC power is pumped into the distribution grid. The Solar PV system is composed of two main components 1) Solar arrays 2) Power conditioning unit (PCU) as shown in the figure1

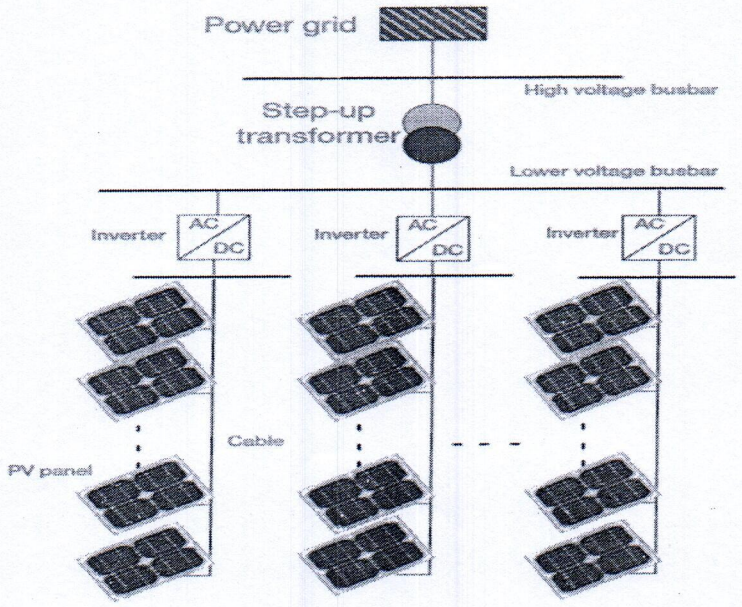

Figure 1 Solar PV system

The renewable energy sources are unpredictable and variable in nature. Moreover the distribution grid is not designed to accommodate high penetration of these sources. Such penetration poses various technical challenges. The allowable limit of Electrical Parameters at PCC during Normal Operation is given below, which should not violate during integration of renewables.

Phenomenon	Limit LV
Frequency	50Hz $\pm$ 1% for 99.5% of time.
Voltage Change	$\pm$ 5% of nominal voltage
Flicker	Long term flicker magnitude $P_h \leq 1$
Unbalance	Negative sequence component has to be within 0 to 2% of positive sequence component for 95% of 10 min mean values.
Harmonics	THD $\leq$ 4%

4 TECHNICAL CHALLENGES IN SOLAR PV INTEGRATION

Integration of solar PV to the conventional grid system poses various challenges as listed below

- Lack interconnection rules and Grid codes.
- Low voltage ride through capability (LVRT).
- Risk of voltage collapse for lack of reactive power support.
- Changes in feeder voltage profiles, including voltage rise and unbalance.
- Changes in feeder loading, including potential equipment and component overload.
- Frequent operation of voltage-control and regulation devices, such as load tap changers (LTCs), line voltage regulators (VRs), and capacitor banks.
- Reactive-power flow fluctuations due to operation of switched capacitor banks.
- Power quality (Harmonics & frequency variation), Solar PV intermittency may lead to voltage fluctuation issues.
- Protection system mal-operation or fail to operate.
- Change in electric losses, where relatively large reverse power flow may increase losses.
- Variations in power factor of a feeder or system, which may have economic impacts on local distribution companies purchasing power from larger utilities.
- Electromagnetic Compatibility, Islanding.
- Reliability and operation of the system.

System operation has main objective is to maintain adequate voltages throughout the transmission and distribution system for both current and contingency conditions to avoid the voltage collapse. At very low levels of system load, transmission lines act as capacitors and increase voltages. At high levels of load

the lines absorb reactive power and thereby lower voltages. In order to regulate voltage and reactive power the devices used are classified as

- Tap-changing transformer
- Shunt capacitors
- Series capacitors
- Shunt reactors
- Synchronous condensers
- SVC
- STATCOM

5 LITERATURE SURVEY

Exhaustive Literature Survey to address the various integration issues and challenges is done which is briefly presented here as per the reference list attached

- General introduction and need for integration: Ref [1]
- Voltage Rise, Regulation and Unbalance: Ref [2-37], total 36 papers
- Harmonics and Power Quality: Ref [38-53], total 16 papers
- Faults and System Protection: Ref [54-79], total 26 papers
- Miscellaneous Issues: Like EMI, Ref [80-84], total 5 papers

  Total – 84 References

6 PROPOSED RESEARCH WORK PLAN

In his research plan various objectives are as follows:

- Modeling of a future grid that will include a significant amount of distributed renewable energy generation, mainly from Solar PV systems.
- To study the various challenges like voltage and reactive power control, Fault Ride-Through Capability enhancement on the power distribution grid.
- Optimal Placement and Sizing of Solar PV in Smart Grid system.
- To study the effect of grid-connected Solar PV systems on power quality.
- Mitigation measures to reduce or minimize the impacts caused by Solar PV integration in order to achieve the Smart Grid goals.

Time plan of the above research methodology

Sr. No.	Activity	Time (in Months)
1	Course Work	6
2	Literature Survey	6
3	Modeling of future grid that will include a significant amount of distributed renewable energy generation, mainly from Solar PV systems	4
4	study of the various challenges of Solar PV integration on the power distribution grid.	6
5	Optimal Placement and Sizing of Solar PV in Smart Grid system	4
6	To study the effect of grid-connected Solar PV systems on power quality.	5
7	Mitigation measures to reduce or minimize the impacts caused by Solar PV integration in order to achieve the Smart Grid goals.	4
8	Thesis writing of research work	6
	Total Time (in Months)	41

7 RESEARCH PROGRESS

Paper Published in Scopus Indexed Journal Title : Challenges & Control Opportunities in the Integration of Solar Energy into the Smart Grid: A Survey **J.V. Desai, Pradeep Kumar Dadhich and P.K. Bhatt** ; International Journal of Applied Engineering Research , ISSN 0973-4562 Volume 10, Number 9 (2015) pp. 24713-24725

REFERENCES

- [1] S. Chowdhury, S.P. Chowdhury and P. Crossley, "Microgrids and Active Distribution Network". London: IET, 2009.
- [2] J. Driesen,and R. Belmans, "Distributed Generation: Challenges and Possible Solutions". IEEE Power Engineering Society General Meeting, pp. 1–8, 2006.
- [3] Y. Liu, J. Bebic, B. Kroposki, J. De Bedout, and W. Ren, "Distribution system voltage performance analysis for high- penetration PV," in IEEE Energy 2030 Conference, 2008. ENERGY 2008, pp. 1–8, Nov. 2008.
- [4] J. H. R. Enslin, "Network Impacts of High Penetration of Photovoltaic Solar Power Systems", IEEE Power Engineering Society General Meeting, pp. 1–5, July 2010.
- [5] F. Katiraei and J.R. Aguero, "Solar PV Integration Challenges," IEEE Power and Energy Mag., vol. 9, no. 3, pp. 62- 71, May-June 2011.
- [6] V. Cecchi, S. Kamalasadan, J.H.R. Enslin, and M. Miller: "Grid Impacts and Mitigation Measures for Increased PV Penetration Levels using Advanced PV Inverter Regulation", in Proc. IEEE Energy Conversion Congress & Expo (ECCE), Denver, CO, USA, 15- 19 September 2013.
- [7] J. Pfitzer, W. E. Dillon, S. Ramesh and T. H. Shen, "Impact of Residential Utility Interactive Photovoltaic Power Systems onthe Utility", Sandia National Laboratory Report No. SAND84- 7008, Sept. 1986.
- [8] W. Jewell and R. Rama kumar, "The Effects of Moving Clouds on Electric Utilities with Dispersed Photovoltaic Generation", IEEE Trans. on Power Apparatus and Systems, vol. PER-7, no. 12, December 1987.
- [9] R. Wai and W. Wang, "Grid-connected photovoltaic generation systems," IEEE Transactions on Circuits and Systems – 1: Regular Papers, vol. 55, no. 3, April 2008.
- [10]B. H. Chowdhury, and S. Rahman, "Is Central Station Photovoltaic Power Dispatchable," IEEE Transactions on Energy Conversion, vol. 3, no. 4,pp.747 – 754, December 1988.
- [11]W. T. Jewell, R. Rama kumar, and S. R Hill, "A Study of Dispersed Photovoltaic Power generation on the PSO System," IEEE Transactions on Energy Conversion. vol. 3, no 3, pp473-478, September 1988,
- [12] E.C. Kern Jr., E.M. Gulachenski, and G.A. Kern, "Cloud effects on distributed photovoltaic generation: slow transients at the Gardner, Massachusetts photovoltaic experiment", IEEE Transactions on Energy Conversion, vol.4, no.2, pp.184-190, June 1989.
- [13]W. T. Jewell and T. D. Unruh, "Limits on clouds-Induced Fluctuation in Photovoltaic Generation," IEEE Transactions on Energy Conversion. vol. 5, no. 1, pp. 8-14, March 1990.
- [14]H. Matsuda, "Interconnecting Dispersed Photovoltaic Power Generation Systems with Existing Utility Grid:A Study at Rokko Inland Test Facility, Japan" International Journal of solar Energy, vol. 13, pp.1-10, 1992.
- [15]A. Woyte, V. V. Thong, R. Belmans, and J. Nijs, "Voltage Fluctuations on Distribution Level Introduced by Photovoltaic Systems" , IEEE Transactions on Energy Conversion, vol. 21, no. 1, pp. 202-209, March, 2006.
- [16]Y. T. Tan, D. S. Kirschen, N. Jenkins, "Impact of Large Penetration of Photovoltaic Generation on the Power System",17th International Conference of Electricity Distribution (CIRED), Barcelona, Spain, 12-15 May 2003.
- [17]D. L. Garrett and S.M. Jetter, "A photovoltaic Voltage Regulation Impact Investigation Technique: Part I - Model Development", IEEE Transactions on Energy Conversion, vol. 4, no. 1, pp. 47-53, March 1989.
- [18]B. Bletterie and T. Pfajfar, "Impact of photovoltaic generation on voltage variations: how stochastic is PV?" In19th International Conference on Electricity Distribution (CIRED),Vienna, May 2007.

[19]G.K Ari and Y. baghzouz "Impact of High PV Penetration on Voltage Regulation in Electrical Distribution Systems" In International Conference on Clean Electrical Power(ICCEP),pp. 744-748, June 2011.

[20]R.A. Shalwala, and J.A.M. Bleijs "Impact of Grid-Connected PV Systems on Voltage Regulation of a Residential Area Network in Saudi Arabia" Proceedings of the 1st International Nuclear and Renewable Energy Conference (INREC10), Amman, Jordan, March 21-24, 2010.

[21]Wei-Lin Hsieh, Chia-Hung Lin, Chao-Shun Chenet al. "Impact of PV Generation to Voltage Variation and Power Losses of Distribution Systems" 4th International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT), July 2011.

[22]Reinaldo Tonkoski, et al. "Impact of High PV Penetration on Voltage Profiles in Residential Neighborhoods", IEEE Transactions on Sustainable Energy, vol. 3, no. 3, pp. 518 – 527, July 2012

[23]S. Ali, N. Pearsall and G. Putrus "Impact of High Penetration Level of Grid-Connected Photovoltaic Systems on the UK Low Voltage Distribution Network" International Conference on Renewable Energies and Power Quality (ICREPQ'12)Santiago de Compostela (Spain), 28th to 30th March 2012.

[24]P. Chen, R. Salcedo, Q. Zhu et al., "Analysis of voltage profile problems due to the penetration of distributed generation in low-voltage secondary distribution networks," IEEE Transactions on Power Delivery, vol. 27, no. 4, pp. 2020–2028, September 2012.

[25]Marcelo Pais, M.E. Almeida and Rui Castro "Voltage Regulation in Low Voltage Distribution Networks with Embedded Photovoltaic Micro generation" International Conference on Renewable Energies and Power Quality (ICREPQ'12) Santiago de Compostela (Spain), 28th to 30th March, 2012.

[26]Yasmin Nigar , Ashish. P. Agalgaonkar, and PhilCiufo, "Impact of Variable Solar PV Generation on MV Distribution Systems", Australian Universities Power Engineering Conference, AUPEC 2014, Curtin University, Perth, Australia, 28 September – 1 October , 2014

[27]F. Favuzza, et al. "Comparison of power quality impact of different photovoltaic inverters: the viewpoint of the grid" , In Proc. 2004 IEEE International Conference on Industrial Technology, Hammamet, Tunisia, , pp. 542–547, December, 2004.

[28]I. El-Samahy, E. El-Saadany, "The effect of DG on power quality in a deregulated environment", In Proc. 2005 IEEE Power Engineering Society General Meeting, San Francisco, CA, USA, pp. 2969–2976, June 2005.

[29]A. Woyte, R. Belmans, and J. Nijs, "Fluctuations in instantaneous clearness index: analysis and statistics", Solar Energy, vol. 81, no. 2, pp. 195–206, February 2007.

[30]IEEE St. 1547.2, Application Guide for IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems, 2008.

[31]T. Kondo, J. Baba, and A. Yokoyama, "Voltage control of distribution network with a large penetration of photovoltaic generation using FACTs devices", Electrical Engineering in Japan , vol. 165, no.3, pp. 16–28, November 2008.

[32]H.S.Goh, M. Armstrong, and B. Zahawi, "The effect of grid operating conditions on the current controller performance of grid connected photovoltaic inverters", In Proc. 13th European Conference on Power Electronics and Applications, Barcelona, Spain, pp. 1–8, September 2009.

[33] L. Chen, S. Qi, and H. Li, "Improved Adaptive Voltage Controller for Active Distribution Network Operation with Distributed Generation," In Proceedings of the 47th International Universities Power Engineering Conference (UPEC '12), London, UK, pp. 1–5, September 2012.

[34] B. Bletterie, et al., "Impact of large photovoltaic penetration on the quality of supply a case study at a photovoltaic noise barrier in Austria", In Proc. 19th European Photovoltaic Solar Energy Conference and Exhibition, Paris, France, pp. 3028–3033, June 2004.

[35] Sarat Chandra Vegunta , Peter Twomey, and Dan Randles " Impact of PV and Load Penetration on LV Network Voltages and Unbalance and Potential Solutions" In Proc. 22nd International Conference On Electricity Distribution Stockholm, 10-13 June 2013.

[36] G. Chicco, J. Schlabbach, and F. Spertino, "Experimental assessment of the waveform distortion in grid-connected photovoltaic installations" Solar Energy vol. 83, no.7 ,pp. 1026–1039, July 2009.

[37] D Parmar, and L. Yao, "Impact of unbalanced penetration of single phase grid connected photovoltaic generators on distribution network." In Proc. 46th International Universities Power Engineering Conference (UPEC), pp. 1-8, September 2011.

[38] A. Ghosh, and G. Ledwich, "Power quality enhancement using custom power devices". Boston: Kluwer Academic Publishers, 2002.

[39] K.W. Louie, et al., "Discussion on power system harmonic analysis in the frequency domain," In Proceedings of the IEEE PES Transmission and Distribution Conference and Exposition: Latin America(TDC '06), pp. 1-6, August 2006.

[40] "IEEE recommended practices and requirements for harmonic control in electrical power systems," IEEE Std. 519- 1992, IEEE, 1993.

[41] P.J.M. Heskes, J.H.R. Enslin, "Power quality behavior of different photovoltaic inverter topologies", In Proc. 24th Power Conversion & Intelligent Motion Conference, Nurnberg, Germany, pp. 1–10, May, 2003.

[42] A.R. Oliva, and J.C. Balda, "A PV dispersed generator: a power quality analysis within the IEEE 519", IEEE Transactions on Power Delivery, vol. 18, no. 2, pp. 525–530, 2003.

[43] M.C. Benhabib, J.M.A. Myrzik, and J.L. Duarte, "Harmonic effects caused by large scale PV installations in LV network", In Proc. 9th International Conference on Electrical Power Quality and Utilization, Barcelona, Spain, pp.1–6, October 2007.

[44] I.T. Papaioannou, et al., "Harmonic impact of small photovoltaic systems connected to the LV distribution network", In Proc. 5th International Conference on European Electricity Market, Lisbon, Portugal, pp. 1–6, May 2008.

[45] W.N. Macedo, R. Zilles, "Influence of the power contribution of a grid-connected photovoltaic system and its operational particularities", Energy for Sustainable Development, vol. 13, no.3 , pp. 202–211, September 2009.

[46] Alejandro R. Oliva and Juan Carlos Balda "A PV Dispersed Generator: A Power Quality Analysis within the IEEE 519" IEEE Transactions on Power Delivery, vol. 18, no. 2, pp.525-530, April 2003.

[47] Johan H. R. Enslin and Peter J. M. Heskes "Harmonic Interaction Between a Large Number of Distributed Power Inverters and the Distribution Network", IEEE Transactions on Power Electronics, vol. 19, no. 6, pp 1586-1593, November 2004.

[48] David G. Infield et al. "Power Quality From Multiple Grid Connected Single-Phase Inverters" IEEE Transactions on Power Delivery, vol. 19, no. 4, pp 1983-1989, October 2004.

[49] Ioulia T. Papaioannou et al. "Harmonic Impact of Small Photovoltaic Systems Connected to the LV Distribution Network" 5th International Conference on European electricity market, pp 1-6. May 2008.

[50] M. McGranaghan, S. Peele, and D. Murray, "Solving harmonic resonance problems on the medium voltage system," In Proceedings of the 19th International Conference on Electricity Distribution, pp. 1–4, 2007.

- [51] F.Wang, J. L. Duarte, and M. A. M. Hendrix, "Analysis of harmonic interactions between DG inverters and polluted grids", In Proceedings of the IEEE International Energy Conference and Exhibition (Energy Con '10), pp. 194–199, December 2010.
- [52] Han Bao, Shaoqing Ying and Harald Schwarz, "Harmonic Impact of Decentralized Photovoltaic Systems and Limitation of Photovoltaic Capacity in Low Voltage Grid", In Proceedings of the IEEE International Conference on Environment and Electrical Engineering , pp.1-4, May 2014.
- [53] I. M. El-Amin and M. Khaleel Ahmed "Impact of a PV System on a Power Grid", IEEE International Symposium on Power Electronics, Electrical Drives, Automation and Motion, pp. 966-970, 18-20 June2014.
- [54] M. Calais, N. Wilmot, A. Ruscoe, O. Arteaga, and H. Sharma, "Over-current protection in PV array installations," presented at the ISES-AP - 3rd International Solar Energy Society Conference- Asia Pacific Region (ISES-AP-08) Sydney, 2008.
- [55] D. E. Collier and T. S. Key, "Electrical Fault Protection for a Large Photovoltaic Power Plant Inverter," in Photovoltaic Specialists Conference, 1988., Conference Record of the Twentieth IEEE, pp. 1035-1042, vol.2, 1988.
- [56] Y. Tang, et al., "Generalized Design of High Performance Shunt Active Power Filter with Output LCL Filter," IEEE Trans. Ind. Electron., vol. 59, no. 3, pp. 1443–1452, March 2012.
- [57] W. Wu, Y. He, and F. Blaabjerg, "An LLCL Power Filter for Single-Phase Grid-tied Inverter," IEEE Tran. Power Electron., vol. 27, no. 2, pp. 782–789, February 2012.
- [58] W. Bower and J. Wiles, "Investigation of Ground-fault Protection Devices for Photovoltaic Power System Applications," In Photovoltaic Specialists Conference, 2000. Conference Record of the28th IEEE, pp. 1378-1383, 2000.
- [59] S. K. Firth, K. J. Lomas, and S. J. Rees, "A Simple Model of PV System Performance and its Use Infault Detection," Elsevier - solar energy, vol. 84, no. 4, pp 624-635, April 2010.
- [60] XiaoliXu, Huan Wang, YunboZuo, "Method for diagnosing PV array fault in Solar PV System", Asia Pacific Power and Energy Engineering Conference, 25-28 March 2011.
- [61] T. Markvart and L. Castaner, "Practical Handbook of Photovoltaic: Fundamentals and Applications" UK: Elsevier Advanced Technology, The Boulevard. Langford Lane, Kidlington, Oxford, OX5lGB, 2012.
- [62] "The Interconnection of Photovoltaic Power Systems with the Utility Grid: An Overview for Utility Engineers" SAND94–1057Unlimited Release UC–276, 1994.
- [63] Enrique Romer Cadaval, et al. "Grid-Connected Photovoltaic Generation Plants, Components and Operation", 6 IEEE industrial electronics magazine, pp 6-20, September 2013.
- [64] Benoit Bletterie, Roland Bruendlinger, Christoph Mayr "Impact of power quality disturbances on PV inverters – Performance of integrated protective functions", In European conference on Power Electronics and Applications , pp 1-10, 2-5 September, 2007.
- [65] T.H. Ortmeyer, K.R. Chakravarthi, A.A. Mahmoud, "The effects of power system harmonics on power system equipment and loads", IEEE Transactions on Power Apparatus and Systems, vol.104, no.9,pp. 2555–2563, September 1985.
- [66] J. de la Cruz, P. Gómez, "Real problems in utility high voltage network due togrid connected photovoltaic power generation. The experience of Endesa", In Proc. 2010 International Conference on Renewable Energies and Power Quality Granada, Spain, pp. 1–6, March 2010.
- [67] X. Chen and J. Sun, "A study of renewable energy system harmonic resonance based on a DG test-bed", In Proceeding of the 26th Annual IEEE Applied Power Electronics Conference and Exposition (APEC'11), pp. 995– 1002, FortWorth, Tex, USA, March 2011.

- [68] Ward Bower et al. "Investigation of Ground-Fault Protection Devices for Photovoltaic Power Systems Applications" IEEE 28th Photovoltaic Specialist Conference, pp 1378-1383, 2000.
- [69] Hyeonseok Park et al. "Optimal Method for Mal-Function for Protective Devices in Distribution Systems Interconnected with PV systems", IEEE T&D Conference and Exposition Asia and Pacific, pp 1-4, 2009.
- [70] Ye Zhao et al. "Fault Analysis in Solar PV Arrays Under: Low Irradiance Conditions and Reverse Connections" IEEE 37th Photovoltaic Specialists Conference, pp 2000-2005, 2011.
- [71] S. Phuttapatimok et al. "Evaluation of fault contribution in the presence of PV grid-connected systems" IEEE 33rd Photovoltaic Specialists Conference, pp 1-5, 2008.
- [72] Yuan-Kang Wu , Shao-Hong Tsai and Ming-Yan Zou "Accommodating High PV Penetration on the Distribution System of Kinmen Island" Energy and Power Engineering, no. 5, pp. 209-214, July 2013.
- [73] Dugan R. and T.E. McDermott. "Operating conflicts for distributed generation on distribution systems", In Rural Electric Power Conference, pages A3/1 A3/6, 2001.
- [74] Dugan R. and T.E. McDermott, "Distributed generation", IEEE Industry Applications Magazine, vol. 8, no. 2, pp.19-25, March / April 2002.
- [75] H. Cheung, A. Hamlyn, L. Wang, C. Yang, R. Cheung, "Investigations of impacts of distributed generations on feeder protections", IEEE PES General Meeting , pp. 1-7, 26-30 July 2009.
- [76] Ye Zhao et al. "Line–Line Fault Analysis and Protection Challenges in Solar Photovoltaic Arrays", IEEE Transactions on Industrial Electronics, vol. 60, no. 9, pp. 3784-3795, September 2013.
- [77] Nguyen Hoang Viet and Akihiko Yokoyama "Influence of Penetration Levels and Fault Ride-Through Characteristics of Photovoltaic Generation on Voltage Stability" Journal of International Council on Electrical Engineering Vol. 3, No. 4, pp.283-289, 2013.
- [78] Antoniosc Marinopoulos et al. "Grid Integration Aspects of Large Solar PV Installations: LVRT Capability and Reactive power/Voltage support Requirements", IEEE Conference Trondheim Power Tech., pp 1-8, 2011.
- [79] Jens. C. Boemer et al. ,"Overview of German Grid Issues and Retrofit of Photovoltaic Power Plants in Germany for the Prevention of Frequency Stability Problems in Abnormal System Conditions of the ENTSO-E Region Continental Europe"1st International Workshop on Integration of Solar Power into Power Systems, Aarhus, Denmark, 24 October 2011.
- [80] Norbert Henzel and Thomas Degner "Radio Interference of Photovoltaic Power Systems" 16th International Wroclaw Symposium and Exhibition on EMC, Wroclaw, Poland, pp 1-6, June 25 - 28, 2002.
- [81] Djilali Hamza, and Praveen Jain "Conducted Electromagnetic Emissions Analysis in Grid-tied PV System" ,IEICE , pp 233-236, 2009.
- [82] Rodolfo Araneo et al. "EMC Issues in High-Power Grid-Connected Photovoltaic Plants" IEEE Transactions in Electromagnetic Compatibility, vol. 51, no. 3,pp. 639-648, August 2009.
- [83] H. Liu et al. "Impact of high penetration of solar photovoltaic generation on power system small signal stability", In International Conference on Power System Technology (POWERCON), pp. 1–7, October 2010.
- [84] Sigifredo Gonzalez, Jason Neely and Michael Ropp "Effect of Non-unity Power Factor Operation in Photovoltaic Inverters Employing Grid Support Functions" IEEE 40th Photovoltaic Specialists Conference (PVSC), pp. 1498-1503, 8-13 June 2014.